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Fuel Cells '96
DOE/EE Transportation Perspective

Donna M. Lee (Donna.Lee@hq.doe.gov; 202-586-8000)
U.S. Department of Energy, EE-32
1000 Independence Ave, NW
Washington, DC 20585

Abstract

Fuel cells represent a developing technology which could potentially replace the internal combustion engine in all areas of the transportation sector. They operate with significantly higher fuel efficiency, greatly reduced emissions, and the capability of running on a variety of fuels (such as hydrogen, ethanol, methanol, and natural gas). The widespread introduction and use of fuel cell vehicles could have a major impact on reducing petroleum consumption and on improving air quality in urban areas. This paper provides an update on the status of the U.S. Department of Energy (DOE) program directed at the development of fuel cell propulsion systems for transportation applications.

Background

Technology Benefits (Energy, Environment, Economy). The United States consumes more petroleum for transportation than for any other energy use. Transportation accounts for one-fourth of all U.S. energy consumption and two-thirds of its petroleum use. The transportation sector is also a major source of air pollution; responsible for about half of the pollutants that form smog in our cities. Moreover, these adverse energy and environmental impacts are forecast to worsen; increases in vehicles and the miles traveled per vehicle" will probably offset the gains resulting from greater energy efficiency and better emission controls in new vehicles, Fuel cells in transportation can be a key technology to combat, these adverse energy, environmental and economic impacts:

Fuel cells can dramatically lower energy use. The operating, efficiency of fuel cell propulsion systems is expected to be as high as 65%, compared with approximately 30% to 35% for current internal combustion engine systems. (Fundamental laws of thermodynamics limit the maximum efficiency of turbines and internal combustion engines. As electrochemical devices, fuel cells have an inherently higher maximum theoretical efficiency.)

Fuel cells can dramatically lower air pollution. The emissions of regulated pollutants from a fuel cell vehicle using methanol would be about 100 times below current and proposed national standards. In addition, increased efficiency can decrease the emission of greenhouse gases, which are not regulated but have an adverse effect on the climate. (Fuel cells produce power without chemical combustion, and thus are inherently cleaner than internal combustion engines.)

Fuel cells can increase use of alternative fuels. Fuel cells are capable of running on hydrogen or fuels from which hydrogen is detached such as ethanol, methanol, gasoline, and natural gas. Decreasing the amount of imported petroleum could ease the trade deficit and increase national security. Decreasing the amount of domestic petroleum usage could promote low cost, highly efficient use of our resources.

Fuel cell vehicles in widespread use would enhance U.S. leadership in fuel cell development and manufacturing and also create anew growth industry along with jobs for a stronger U.S. economy.

Program History. The Department of Energy recognized the potential of fuel cells for transportation applications and began development of a phosphoric acid fuel cell (PAFC) powered bus in 1987. The transit bus platform was chosen because it offered the most flexibility in packaging the fuel cell and auxiliary component technology available at that time. By 1990, the proton-exchange-membrane (PEM) fuel cell had demonstrated sufficient progress in performance, and thus a light-duty fuel cell vehicle program was launched with General Motors. Methanol was selected as the fuel because of its availability, simplicity of storage, rapid refueling, high energy density, and ability to be easily reformed. In addition, serious consideration has been given to other fuel options, including hydrogen and petroleum. In 1994, DOE initiated programs with two industry teams led by Ford and Pentastar (a Chrysler subsidiary) to develop direct hydrogen-fueled PEM fuel cell propulsion systems. In 1995, a contract was awarded to Arthur D. Little, Inc. to develop a flexible-fuel processor capable of reforming gasoline and other common transportation fuels. Throughout its short history, the DOE program has continued to support exploratory research on critical fuel cell components and materials to address technological barriers to commercialization,

Program Drivers, This program is responsive to requirements of the U.S. Energy Policy Act of 1992 (EPACT) which authorizes the development of fuel cell vehicles. It also represents the key fuel cell work being done under the Partnership for a New Generation of Vehicles (PNGV) --a U.S. government/industry research and development initiative involving representatives from seven Federal agencies and the Big Three automakers (Chrysler, Ford, General Motors) that began in 1993 to strengthen U.S. competitiveness in the automotive industry. DOE's program specifically addresses the PNGV goal of developing a vehicle to achieve up to three times the fuel efficiency of today's comparable vehicle. Besides the legislative drivers for this program, there is keen international competition in the race to develop PEM power systems for automobiles -- extensive efforts are underway in North America, Europe and Japan. Daimler-Benz of Germany recently unveiled their second-generation prototype van powered by a 50-kW PEM fuel cell; and Japanese auto companies are expected to unveil fuel cell vehicles later this year.

Program Goal

The goal of the DOE Fuel Cells in Transportation Program is to develop highly efficient, low or zero emission automotive fuel cell propulsion systems. Specific objectives include: By the year 2000, validate fuel cell propulsion systems that are (a) 2-3 times more energy efficient than today's comparable vehicles; (b) more than 100 times cleaner than Federal EPA Tier II emissions standards; and (c) capable of operating on hydrogen, methanol, ethanol, natural gas, and gasoline. In addition, by the year 2004, our objective is to validate fuel cell propulsion systems that meet customer expectations in terms of cost (competitive with conventional vehicles) and performance (equivalent range, safety, and reliability as conventional vehicles).

Program Challenges

In order for fuel cell propulsion systems to reach their potential, significant technical challenges must be met, including: size and weight reduction, rapid start-up and transient response capability, fuel processing development, manufacturing cost reduction, complete fuel cell system integration, and durability and reliability demonstration. Non-technical barriers to fuel cell vehicle commercialization include the lack of capital investment for large-scale fuel cell vehicle production, the lack of an alternative fuel infrastructure, the lack of consumer awareness, the lack of industry standards for mass production and servicing, and the lack of safety regulations.

Program Strategy

The program strategy is to work with all stakeholders by means of a National Fuel Cell Alliance. This government/industry alliance includes domestic automakers, component suppliers, fuel cell developers, national laboratories, universities, and the fuels industry. Currently, under the alliance, each of the three domestic automakers are pursuing different technical approaches by means of cost-shared research projects with DOE. Additionally, pre-competitive fuel cell R&D managed by DOE will attempt to resolve fundamental problems and issues associated with fuel cells and ancillary components that apply to a number of different fuel cell propulsion systems. Each automaker team will have access to the technology and products resulting from the pre-competitive R&D. The Fuel Cell Alliance approach has significant benefits for both DOE and America's automakers. By sharing the results of pre-competitive R&D, government and industry will be able to leverage research dollars. By maintaining their own independent vehicle integration team, the automakers will be able to pursue the approaches which they believe provide the greatest payoffs.

With many technical barriers to overcome and a limited budget to work with, the DOE program has been compelled to streamline its scope and focus its resources. In a recent planning workshop, industry and laboratory experts reviewed the program and developed a recommended list of the R&D priorities and a preliminary fuel strategy for fuel cells in transportation. Fuel processing, fuel cell stack components (such as membranes, catalysts, and bipolar plates), and system components (such as heat exchangers, compressor/expanders) are areas where focussed R&D is needed. Currently, DOE funds three industry teams having an automaker as the prime contractor and fuel cell suppliers as subcontractors. As these system development contracts end in 1997, a different program approach will be in place. DOE will contract directly with fuel cell suppliers and component developers, thus allowing all automakers access to the improvements being made among the suppliers.

Major Projects

CONTRACT	OBJECTIVE	LENGTH
General Motors	Methanol-fueled, fully integrated PEM system	30months
Ford	Hydrogen-fueled PEM system based on full performance approach	39 months
Chrysler	Hydrogen-fueled PEM system based on desi W-to-cost approach	36 months
A.D. Little	Petroleum-Based Fuel Processor	12 months
National Labs: LANL, LBNL, BNL, ANL	Exploratory Fuel Cell Component R&D	On-going
International Fuel Cells	Direct Methanol Fuel Cell (DMFC) Stack	12 months
Energy Partners	Novel PEM Stack	18 months
Texas A&M University	**Novel** PEM Stack	12 months
A.D. Little	Scroll Compressor/Expander	15 months
Vairex	Variable Piston Compressor/Expander	15 months
Allied Signal	Turbo Compressor/Expander	15 months

Current Status

Fuel Cell Propulsion System Development

General Motors (GM) completed a three-year effort in 1993 which demonstrated proof-of-feasibility for methanol-fueled, proton-exchange-membrane (PEM) fuel cells as an electrochemical engine for transportation applications. The GM program is currently in Phase II, which will result in the demonstration of a 50-kW system. Advancements are being made in three areas. In the fuel processing area, the design of a 50-kW reformer is complete; a new reformer catalyst with twice the activity of the best previously known reforming catalyst has been identified (reducing cost and size). In the fuel cell stack area, GM demonstrated 500 hours of single cell operation of coated titanium bipolar plates (which are lighter and less costly than machined graphite plates); developed a coating process for metallic bipolar plates and subsequently filed an invention record; and fabricated and tested electrodes with ultra-low platinum loadings which is critical in cost reduction. In the system integration area, stand-alone operation of the 10-kW PEM fuel cell system was achieved using a Powerex air compressor-expander, and real-world automotive components such as fluid injectors and pressure regulators. The General Motors development team includes the General Motors Research and Development Center as prime contractor and several participating divisions of Delphi Automotive S ystems, namely, Delphi Energy and Engine Management Systems (formerly AC Rochester), Delphi Harrison, Delphi Packard, and Delco Electronics. Key subcontractors include DuPont and Ballard Power Systems.

Ford's Phase I competition among five fuel cell developers is completed. The developers were International Fuel Cells, Energy Partners, H Power Corporation, Mechanical Technologies, and Tecogen. The task was to deliver a 10-kW PEM stack for a direct hydrogen system with a performance goal of 3.7 kg/kW within the one-year time frame. One or two of the developers will continue in Phase II with the design, fabrication and testing of a 50-kW fuel cell system. A preliminary conceptual vehicle design and an extensive hydrogen infrastructure and vehicle safety analysis have been completed. Directed Technologies, Air Products & Chemicals, Praxair Inc., Electrolyser Corporation, and BOC Gases performed the hydrogen-related issues analyses. A new state-of-the-art hydrogen storage tank liner was developed by Lawrence Livermore National Laboratory, EDO Fiber Sciences and Aero Tec Labs. This technology greatly reduces the fuel storage size which is critical in the vehicle design.

Chrysler/Pentastar's fuel cell work, being done by Allied Signal, is focussed on a design-to-cost approach in which materials development plays a critical role. Low-cost bipolar plates and low-cost membranes have been developed. Work is progressing with fabrication of 10-kW stack hardware and durability testing of low-cost bipolar plate materials. Performance problems encountered with the scale-up of the low-cost fuel cell design are being resolved. Scale-up to a 30-kW system is planned by January of 1997. Pentastar is supported by Chrysler Liberty, Allied Signal Aerospace, Allied Signal Automotive, and Allied Signal Research and Technology.

Fuel Processing and Storage R&D

DOE awarded a contract to Arthur D. Little, Inc in 1992 to develop fuel processor systems for reforming methanol, ethanol, natural gas, and other hydrocarbons for use in transportation fuel cell systems, and for development of advanced systems for hydrogen storage on vehicles. This project is intended to provide fuel flexibility for fuel cell powered vehicles, and to reduce fuel processor size and cost, reduce start-up time, and increase transient response capability, Steam reforming, partial oxidation, and combinations of these processes were investigated. In FY 1994, a 25-kW reformer and a 1-kg hydrogen storage proof-of-concept systems were built and tested In FY 1995, a 40-kW partial oxidation (POX) ethanol fuel processor was built and tested; the State of Illinois co-sponsored this effort, In FY 1996, the development effort will culminate in a petroleum-based fuel processor. The main technical challenge is in reducing the carbon monoxide level in the fuel stream, which is a poison to the fuel cell system.

Component R&D

Exploratory research at Los Alamos National Laboratory, Lawrence Berkeley National Laboratory and Brookhaven National Laboratory is focussing on advanced fuel cell concepts such as direct methanol oxidation in low-temperature fuel cells (DMFCs), improved materials and components for PEM, and electrocatalyst research. Two key objectives are reducing catalyst poisoning and methanol crossover. Research at Argonne National Laboratory has resulted in a quick-start, lightweight, compact methanol partial oxidation reformer that will be inexpensive to manufacture. In addition to reformer R&D, Argonne is characterizing alloy catalysts for CO tolerance and electrochemical methanol oxidation, developing a dynamic fuel processor and system model, characterizing novel cathode materials for direct methanol solid oxide fuel cells (SOFC), and modifying a battery test facility to include fuel cell testing capability.

In 1996, six new cost-shared contracts were awarded under a program research and development announcement for novel fuel cell stack development (International Fuel Cells, Texas A&M, Energy Partners) and compressor/expander development (Allied Signal, A.D. Little, Vairex). International Fuel Cells will be developing a conceptual design of a direct methanol fuel cell stack focus sing on methanol impermeable membranes and advanced anode catalysts. Texas A&M University will be developing a small-scale PEM stack addressing low platinum and platinum alloys, advanced membranes, internal humidification concepts, lightweight composite materials, and water/thermal management. Energy Partners will be developing a small-scale PEM stack focussing on bipolar plate flow optimization, cell stack design studies, and low platinum loading membrane-electrode assembly techniques. A.D. Little, Allied Signal, and Vairex will be developing three different prototype compressor/expanders (scroll, turbo, and variable piston, respectively) designed specifically for automotive fuel cell systems.

New Initiatives

The plan for August 1996 is to release anew solicitation for innovative research and development of(1) a complete, integrated fuel cell power system consisting of an advanced fuel-flexible fuel processor that reforms common transportation fuels (e.g., methanol, ethanol, gasoline, and natural gas) and an advanced 50-kW PEM fuel cell stack, and (2) any material, component, or process that will address a single critical issue in developing fuel cell technology for transportation applications.

Conclusion

The future for fuel cell technology looks very promising. Fuel cells have the potential to revolutionize the way in which power is generated for all types of vehicles. With successful development fuel cells could have the equivalent technological impact on society in the first half of the 21 st century as the internal combustion engine did in the first half of the 20th century.